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I, JONNE YABSLEY, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. 2002952681 for a patent by BHP BILLITON INNOVATION PTY LTD as filed on 14 November 2002.

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Fourteenth day of October 2003

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SYSTEM AND METHOD(S) OF MINE PLANNING, DESIGN AND PROCESSING

FIELD OF INVENTION

The present invention relates to the field of extracting resource(s) from a particular location. In particular, the present invention relates to the planning, design and processes related to a mine location in a manner based on enhancing the extraction of material considered of value, relative to the effort and / or time in extracting that material.

BACKGROUND ART

In the mining industry, once material of value, such as ore situated below the surface of the ground, has been discovered, there exists a need to extract that material from the ground.

In the past, one more traditional method has been to use a relatively large open cut mining technique, whereby a great volume of waste material is removed from the mine site in order for the miners to reach the material considered of value. For example, referring to Figure 1, the mine 101 is shown with its valuable material 102 situated at a distance below the ground surface 103. In the past, most of the (waste) material 104 had to be removed so that the valuable material 102 could be exposed and extracted from the mine 101. In the past, this waste material was removed in a series of progressive layers 105, which are ever diminishing in area, until the valuable material 102 was exposed for extraction. This is not considered to be an efficient mining process, as a great deal of waste material must be removed, stored and returned at a later time to the mine site 101, in order to extract the valuable material 102. It is desirable to reduce the volume of waste material that must be removed prior to extracting the valuable material.

The open cut method exemplified in Figure 1 is viewed as particularly inefficient where the valuable resource is located to one side of the pit 105 of a desirable mine site 101. For example, Figure 2 illustrates such a situation. The valuable material 102 is located to one side of the pit 105. In such a situation, it is not considered efficient to remove the waste material 104 from region 206, that is where the waste material is not located relatively close to the valuable material 102, but it is considered desirable to remove the waste material 104 from region 207, that is where it is located nearer to the valuable material 102. This then

brings other considerations to the fore. For example, it would be desirable to determine the boundary between regions 206 and 207, so that not too much undesirable waste material is removed (region 206), yet enough is removed to ensure safety factors are considered, such as cave-ins, etc. This then leads to a further consideration of the need to design a 'pit' 105 with a relatively optimal design having consideration for the location of the valuable material, relative to the waste material and other issues, such as safety factors.

This further consideration has led to an analysis of pit design, and a technique of removing waste material and valuable material called 'pushbacks'. This technique is illustrated in Figure 3. Basically, the pit 105 is designed to an extent that the waste material 104 to be removed is minimised, but still enabling extraction of the valuable material 102. The technique uses 'blocks' 308 which represent smaller volumes of material. The area proximate the valuable material is divided into a number of blocks 308. It is then a matter of determining which blocks need to be removed in order to enable access to the valuable material 102. This determination of 'blocks 308', then gives rise to the design or extent of the pit 105.

Figure 3 represents the mine as a two dimensional area, however, it should be appreciated that the mine is a three dimensional area. Thus the blocks 308 to be removed are determined in phases, and cones, which represent more accurately a three dimensional 'volume' which volume will ultimately form the pit 105.

Further consideration can be given to the prior art situation illustrated in Figure 3. Consideration should be given to the scheduling of the removal of blocks. In effect, what is the best order of block removal, when other business aspects such as time/value and discounted cash flows are taken into account? There is a need to find a relatively optimal order of block removal which gives a relatively maximum value for a relatively minimum effort/time.

Attempts have been made in the past to find this 'optimum' block order by determining which block(s) 308 should be removed relative to a 'violation free' order. Turning to the illustration in Figure 4, a pit 105 is shown with valuable material 102. For the purposes of discussion, if it was desirable to remove block 414, then there is considered to be a 'violation' if we determined a schedule of

block removal which started by removing block 414 or blocks 414, 412 & 413 before blocks 409, 410 and 411 were removed. In other words, a violation free schedule would seek to remove other blocks 409, 410, 411, 412 and 413 before block 414. (It is important to note that the block number does not necessarily indicate a preferential order of block removal).

It can also be seen that this block scheduling can be extended to the entire pit 105 in order to remove the waste material 104 and the valuable material 102. With this violation free order schedule in mind, prior art attempts have been made. Figure 5 illustrates one such attempt. Taking the blocks of Figure 4, the blocks are numbered and sorted according to a 'mineable block order' having regard to practical mining techniques and other mine factors, such as safety etc and is illustrated by table 515. The blocks in table 515 are then sorted 516 with regard to Net Present Value (NPV) and is based on push back design via Life-of-mine NPV sequencing, taking into account obtaining the most value block from the ground at the earliest time. To illustrate the NPV sorting, and turning again to Figure 4, there is a question as which of blocks 409, 410 or 411 should be removed first. All three blocks can be removed from the point of view of the ability to mine them, but it may, for example, be more economic to remove block 410, before block 409. Removing blocks 409, 410 or 411 does not lead to 'violations' thus consideration can be given to the order of block removal which is more economic.

The NPV sorting is conducted in a manner which does not lead to violations of the 'violation free order', and provides a table 517 listing an 'executable block order'. In other words, this prior art technique leads to a listing of blocks, in an order which determines their removal having regard to the ability to mine them, and the economic return for doing so.

The foregoing description and prior art techniques, in as much as the removal of material is concerned, is based substantially on the assumption that the data gathered from sample drillings is an accurate reflection of the homogeneity of the entire mine pit. Unfortunately, in many cases of the prior art, what has been revealed underneath the ground over the life of the mine, has differed from what was 'expected' to be found based on the sample drillings and

geological survey data initially obtained. The difference may manifest itself in grade of material or waste.

Although the difference may be marginal from one block to another, or with regard to a slight variation in grade or quality of ore, when taken globally over a mine project both in magnitude and time, the difference can represent many millions of dollars between what actually was mined, and what was expected when the mine was designed.

One reason for this is that the design of prior art mines is based substantially entirely on this sample, geological survey data. Thus if the data is wrong, or inaccurate, then the design established for the mine will not be found to be optimal for that particular mine location. Again, unfortunately, this will usually only be realised well after the design has been established and implemented. By this time it is, or it may be considered, too late to correct or alter the mine design. The result will be the (wasteful) expenditure of possibly many millions of dollars in creating a mine according to a design that was not 'optimal'.

In considering the problem posed, it will be helpful to gain a better understanding of prior art mine 'design' techniques. In general, a geographical survey establishes data used as the basis of a mine design. The 'design' is necessary to provide determination of the various commercial aspects associated with a mine, and for establishing a block 'schedule'; that is an executable order of blocks from the mine.

This survey data manifests itself in, for example, 10 or 20 different samples and analyses of the potential mine location and site. A number of simulations and interpolations are made based on the data in order to predict a mine plan, which can be considered an order for taking material (ore and / or waste) from the location of the potential mine. It is then necessary to establish 'the' (one) mine plan which is to be implemented.

Typically, the blocks of highest value lie near the bottom of the ore body, far underneath the ground. A cash flow stream is generated when these blocks are excavated and the ore within them is sold. Because one can earn interest on cash received earlier, the value of a block increases if it is excavated earlier, and decreases (or is discounted) if it is excavated later. This concept of discounting is central to the notion of net present value (NPV). Thus the mine planner seeks an

extraction schedule that maximizes the net present value of the ore body. The net present value forms the objective function of this optimization problem.

Calculating the NPV of an extraction schedule is far from easy. In current approaches, each block is simply ascribed a value in dollars, but in many cases, this value may be only a very crude approximation, and subject to change. For commodities such as copper, the planner needs to know the metal content of the block, the selling price at all future times within the planning horizon, the mining/processing costs, and some other factors. This is a difficult and problematic in itself.

In some cases, a random selection may have been made from the simulations and interpolations. An example of this is "AN APPLICATION OF BRANCH AND CUT TO OPEN PIT MINE SCHEDULING" by Louis Caccetta and Stephen P. Hill. A copy may be found at website: http://rutcor.rutgers.edu/~do99/EA/SHill.doc .

In other instances, an 'average' of the various simulations is taken and which assumes a fixed pricing in the interpolation(s) calculated, where the 'average' has been taken as 'the' mine design.

Given the commercial significance of a mine and the relatively large scale nature of a mine, there is a need to improve mine design, the method(s) used to design a mine and / or the selection of a mine design for implementation.

Another object of the present invention is to alleviate at least one disadvantage of the prior art.

Any discussion of documents, devices, acts or knowledge in this specification is included to explain the context of the invention. It should not be taken as an admission that any of the material forms a part of the prior art base or the common general knowledge in the relevant art in Australia or elsewhere on or before the priority date of the disclosure and claims herein.

SUMMARY OF INVENTION

The present invention provides a method of determining the removal of material(s) from a location, including selecting a value of risk, calculating a corresponding return, and determining a schedule corresponding to the risk and / or return.

Other aspects and preferred aspects are disclosed in the specification and / or defined in the appended claims.

In essence, the present invention, a design to be configured to account for (multiple) representations of the mine location and / or ore body based, at least in part, on a risk .vs. return basis.

The present invention may be used, for example, by mine planners to design open cut mines, but the present invention should not be limited to only such an application. Advantageously, the present invention is considered to be different to prior art in that the present invention:

- provides a mining schedule can be found with maximal expected NPV for a given level of risk ,
- does not produce schedules with expected NPV's that are below those possible for given levels of risk,
- the ability to relatively quickly generate and evaluate a number of different sets of candidate pushback designs. Such a feature not allowed for in prior art pushback design software where design options are usually fairly limited (eg: the amalgamation of adjacent Whittle shells into a single pushback),
- can be used in association with a unique concept of optimal "clump" sequencing to develop an optimal block sequence that is then used as a basis for pushback design,
- can be used in association with techniques which are relatively optimal with respect to properly discounted block values. Traditional phase designs ignore medium grade ore pods close to the surface with good NPV whilst focussing on higher value pods that may be deeply buried,
- Process and mining constraints can be explicitly incorporated into the pushback design step,
- The planner can rapidly design and value pushbacks that have different topologies, the trade-off being between pits with high NPV, but with difficult-to-mine (eg: ring) pushback shapes, and those with more mineable pushback shapes but lower NPV. The advantage of the more mineable pushback shapes is that much less NPV will be wasted in enforcing

minimum mining width and in accommodating pit access (roads and berms),

- Various aspects of the present invention also serve to improve the use of existing integer programming engines, such as "cplex" by ILOG.

Throughout the specification:

1. a 'collection' is a term for a group of objects,
2. a 'cluster' is a collection of ore blocks or blocks of otherwise desirable material that are relatively close to one another in terms of space and / or other attributes,
3. a 'clump' is formed from a cluster by first producing a substantially minimal inverted cone extending from the cluster to the surface of the pit by propagating all blocks in the cluster upwards using the arcs that describe the minimal slope constraints. Each cluster will have its own minimal inverted cone. These minimal inverted cones are then intersect with one another and the intersections form clumps,
4. an 'aggregation' is a term, although mostly applied to collections of blocks that are spatially connected (no "holes" in them). For example, a clump may be an aggregation, or may be "Super blocks" that are larger cubes made by joining together smaller cubes or blocks, and
5. a 'panel' is a number of blocks in a layer (bench) within a pushback.

DESCRIPTION OF DRAWINGS

Further disclosure, objects, advantages and aspects of the present application may be better understood by those skilled in the relevant art by reference to the following description of preferred embodiments taken in conjunction with the accompanying drawings, in which:

Figures 1 to 5 illustrate prior art mining techniques, and

Figure 6 illustrates diagrammatically a representation of the present invention and based on a plurality of drill holes and / or survey data.

DETAILED DESCRIPTION

In accordance with the present invention, a design is configured to account for (multiple) representations of the mine location and / or ore body based, at least in part, on a risk .vs. return basis.

The present invention calculates a NPV (which it has been realised can be used as a measure of 'return'). The present invention provides an indication of a relatively 'optimal', or at least a preferred, schedule in the presence of uncertainty. By "schedule" we mean to include at least (i) a schedule of blocks, (ii) a schedule of panels, and / or (iii) a schedule of clumps to form a block sequence and ultimately pushbacks.

In calculating NPV,

let $v_{i,t}(\omega)$ denote a random variable describing the 'value' (in today's dollars) of a block/clump/panel having an identification number i in period t. The randomness can cover factors such as:

- grade uncertainty (t-independent)
- price/cost uncertainty
- recovery uncertainty

Each ω is a sample "reality", by which is meant a 'possible value' of a block/clump/panel over a period of time, with an assigned relative probability of occurring. Reality is a future outcome. The 'actual' price of a block in some future time is not known until that particular period of time. Also, the 'actual' ore/grade of a block is not known until it is actually mined and assayed. Thus, the present invention is implemented having regard to one or more 'possible values'. Each possible value is analysed further. Any variation of $v_{i,t}$ in t will be due substantially to price, cost, or recovery variation over time, not to discounting.

It has been realised, in accordance with the present invention, that since block values are random variables, so too is the NPV. Thus, the NPV for each block/clump/panel can be expressed as expression 1, namely:

$$\mathrm{NPV} = \Sigma\, v_{i,t}(\omega)\ .\ \mathrm{D}\ .\ \mathrm{E} \qquad \text{....expression 1}$$

where:

NPV is the sum of the random block values, appropriately discounted, in as far as, in considering the random block value, an annual (or period) discount factor and the block/clump/panel excavated and processed in the period can be taken into account,

D represents a variable discount for future values of $v_{i,t}(\omega)$, and

E is 1 if the block/clump/panel is excavated and 0 otherwise.

Calculating Return

If risk is ignored, it is reasonable to aim for relatively maximal expected NPV, as noted above. It has been further realised, in accordance with the present invention, that the expected 'return' can be expressed with regard to average block values, namely av($v_{i,t}(\omega)$) and thus the expected return can be expressed as expression 2:

Return (NPV) = $\sum$ av ($v_{i,t}(\omega)$) . D . E ....expression 2

where:

Return (NPV) is the sum of the average block values, appropriately discounted, in as far as, in considering the random block value, an annual (or period) discount factor and the block/clump/panel excavated and processed in the period can be taken into,

av ($v_{i,t}(\omega)$) is average block value,

D represents a variable discount for future values of $v_{i,t}(\omega)$, and

E is 1 if the block/clump/panel is excavated and 0 otherwise.

To utilise the above expression, it may be input to a linear mixed integer program solver. In one embodiment, existing linear mixed integer program solvers may be used to solve a program of the form:

max Return(NPV) ....expression 3

subject to precedence constraints

production rate constraints

The relatively maximum return calculated corresponds to point Z in figure 6.

In dealing with production rate constraints, it has been realised that the production rate constraints are random constraints, as they are linked to ω. Thus, in accordance with one aspect of the present invention, average ore contents can be used in the constraints. Thus the production rate constraints can be expressed as:

$\sum$ av (ore content of block i) (ω). E $\leq$Max tonnes that can be processed in a period, such as 1 year ....expression 4

Controlling risk

A further aspect of the present invention calculates the variance in NPV, which has been realised can be used as a measure of 'risk'. Risk describes the variation of possible outcomes of the random variable NPV. The variance of NPV is therefore considered to be a way to measure risk.

Var(NPV) = F + G ....expression 5

where

F is (variance in $v_{i,t}(\omega)$) . D . E

G is (covariance in $(v_{i,t} v_{j,s})$) . D . E

D represents a variable discount for future values of $v_{i,t}(\omega)$, and

E is 1 if the block/dump/panel is excavated and 0 otherwise.

The value of $\mathrm{var}(v_{i,t})$ and $\mathrm{cov}(v_{i,t} v_{j,s})$ can be provided by the input data from conditional simulations and price models.

In order to utilise the above expression, it is preferred to aim for is relatively maximizing expected NPV, subject to some upper bound on the variance of NPV. This will provide a point on the "efficient frontier" in the "return/risk" plane as represented by the curve illustrated in Figure 6.

In terms of expressing relatively maximum return on NPV:

max	Return(NPV)	....expression 6
subject to	var(NPV) ≤h, h being a risk value	
	precedence constraints	
	production rate constraints	

where h > 0 is some value greater than the minimal risk.

Equivalently, (and conveniently for integer programs), variance of NPV could be relatively minimised subject to an upper bound on the expected NPV. In order to relatively simplify computation of this program, expression 6 can be represented as expression 7, namely:

The quadratic mixed integer program:

min	var(NPV)	....expression 7
subject to	Return(NPV) $\geq c$	
	precedence constraints	

production rate constraints

where $c > 0$ is some value less than or equal to the relatively maximal expected NPV. Also, production rate constraints can be made non-random as before, by using averages, such as average ore contents.

Turning to Figure 6, a mine designer can select the desired risk/return, and then iterate the above expressions to determine the appropriate schedule. In essence, each 'dot' or point on the curve represents or can be used to establish a different 'schedule'. The risk/ return and its corresponding NPV can be used to establish a schedule for the removal of blocks. In Figure 6, vertical lines constraining risk relate to expression 6 above, and horizontal lines constraining return relate to expression 7 above. For example, if a risk is selected to be h_A, then the expressions above can be solved resulting in point A on the curve of Figure 6. This point A gives a first schedule with a corresponding risk and return. Likewise, if a higher risk is selected to be h_B, then the expressions above can be solved resulting in point B on the curve of Figure 6. This point B gives a second schedule with a corresponding risk and return.

In this manner, by use of the present invention, a relatively low risk/ low return or relatively high risk/ high return, and / or a relatively moderate risk/return can be selected as desired by the user. Each risk/return corresponds to a point on the curve, exemplified in Figure 6, which in turn represents a corresponding schedule. Figure 6 also illustrates areas considered too high is risk and areas which are considered practically infeasible. This differs from case to case. From this point, a schedule can be established using known techniques and / or techniques disclosed in corresponding patent application(s) filed by the present applicant 9 October 2002, Australian provisional application numbers PS1099, 2002951892, 2002951957, 2002951894, 2002951891, 2002951893, 2002951896, 2002951898 and 2002951895 and herein incorporated by reference.

While this invention has been described in connection with specific embodiments thereof, it will be understood that it is capable of further modification(s). This application is intended to cover any variations uses or adaptations of the invention following in general, the principles of the invention and including such departures from the present disclosure as come within known

or customary practice within the art to which the invention pertains and as may be applied to the essential features hereinbefore set forth.

As the present invention may be embodied in several forms without departing from the spirit of the essential characteristics of the invention, it should be understood that the above described embodiments are not to limit the present invention unless otherwise specified, but rather should be construed broadly within the spirit and scope of the invention as defined in the appended claims. Various modifications and equivalent arrangements are intended to be included within the spirit and scope of the invention and appended claims. Therefore, the specific embodiments are to be understood to be illustrative of the many ways in which the principles of the present invention may be practiced. In the following claims, means-plus-function clauses are intended to cover structures as performing the defined function and not only structural equivalents, but also equivalent structures. For example, although a nail and a screw may not be structural equivalents in that a nail employs a cylindrical surface to secure wooden parts together, whereas a screw employs a helical surface to secure wooden parts together, in the environment of fastening wooden parts, a nail and a screw are equivalent structures.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method of determining the removal of material(s) from a location, including:

selecting a value of risk,
calculating a corresponding return, and
determining a schedule corresponding to the risk and return.

2. A method as claimed in claim 1, wherein the return corresponds to NPV.

3. A method as claimed in claim 1 or 2, wherein the risk corresponds to variance in NPV.

4. A method as claimed in claim 1, 2 or 3, wherein the return corresponds to the expression:

$$\text{Return (NPV)} = \sum \text{av}\,(v_{i,t}(\omega))\,.\,D\,.\,E$$

where:

av $(v_{i,t}(\omega))$ is average block value,
D represents a variable discount for future values of $v_{i,t}(\omega)$, and
E is 1 if the block/clump/panel is excavated and 0 otherwise.

5. A method as claimed in any one of claims 1 to 4, wherein the risk corresponds to the expression:

$$\text{Var(NPV)} = F + G$$

where:

F is (variance in $v_{i,t}(\omega)$) . D . E
G is (covariance in $(v_{i,t}v_{j,s})$) . D . E
D represents a variable discount for future values of $v_{i,t}(\omega)$, and
E is 1 if the block/clump/panel is excavated and 0 otherwise.

6. A method as claimed in any one of claims 1 to 5, substantially as herein disclosed with reference to Figure 6 of the accompanying drawings.

7. A block, clump and / or panel schedule established in accordance, at least in part, in accordance with the method as claimed in any one of claims 1 to 6.

8. Apparatus adapted to determining the removal of material(s) from a location, said apparatus including:

processor means adapted to operate in accordance with a predetermined instruction set,

said apparatus, in conjunction with said instruction set, being adapted to perform the method as claimed in any one of claims 1 to 6.

9. A computer program product including:

A computer usable medium having computer readable program code and computer readable system code embodied on said medium for determining the removal of material(s) from a location within a data processing system, said computer program product including:

Computer readable code within said computer usable medium for determining, at least in part, a schedule in accordance with claim 7.

10. A computer program product including:

A computer usable medium having computer readable program code and computer readable system code embodied on said medium for determining the removal of material(s) from a location within a data processing system, said computer program product including:

Computer readable code within said computer usable medium for determining, at least in part, a method in accordance with any one of claims 1 to 6.

DATED THIS 14th day of November 2002

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Figure 1
(prior art)

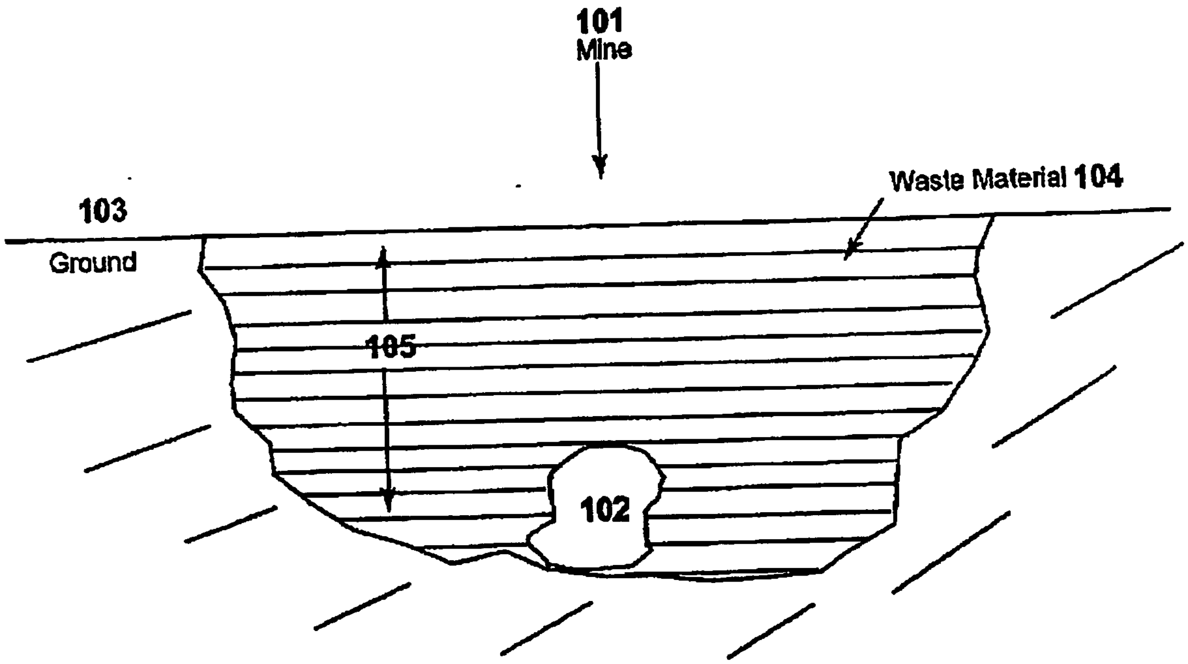


Figure 2
prior art

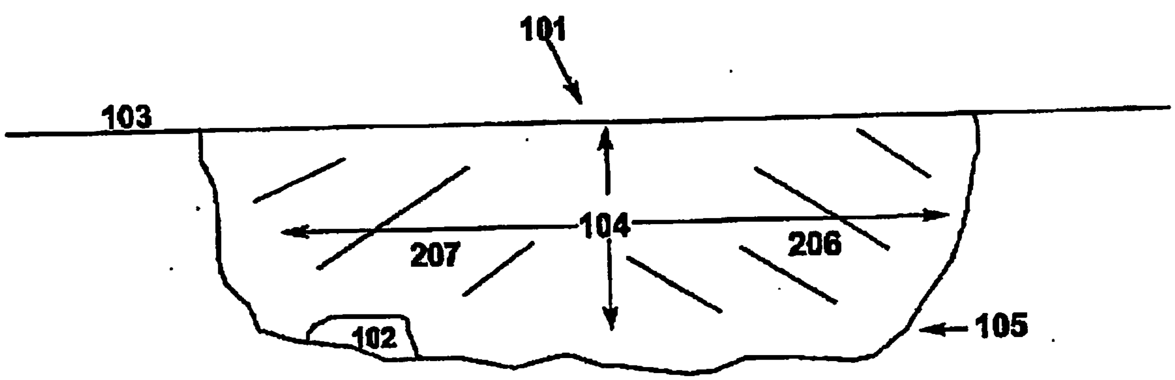
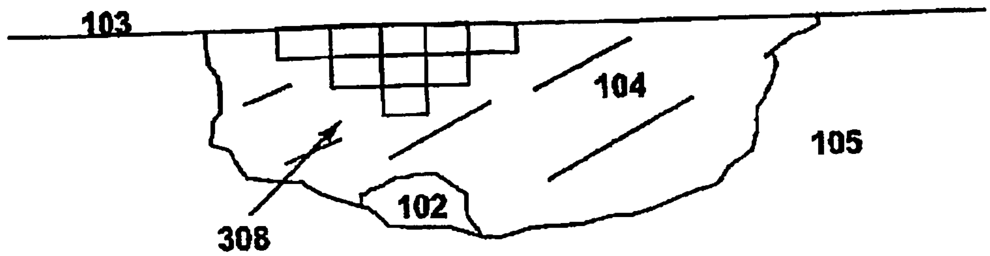


Figure 3
prior art



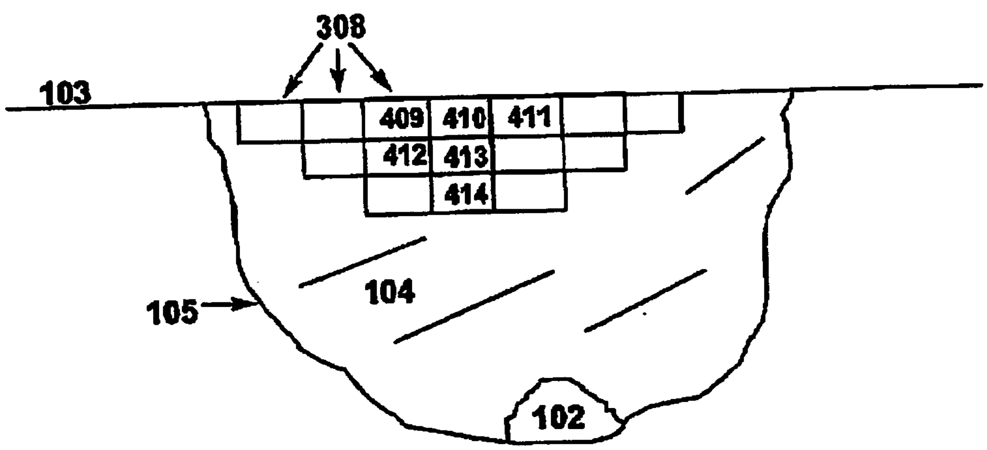


Figure 4
prior art

Figure 5
prior art

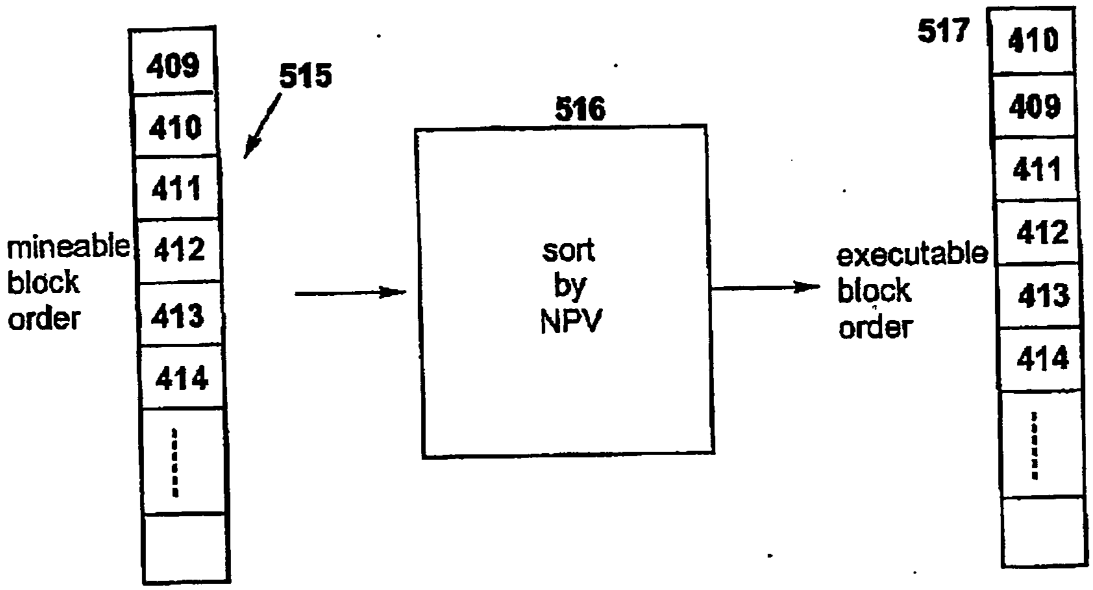
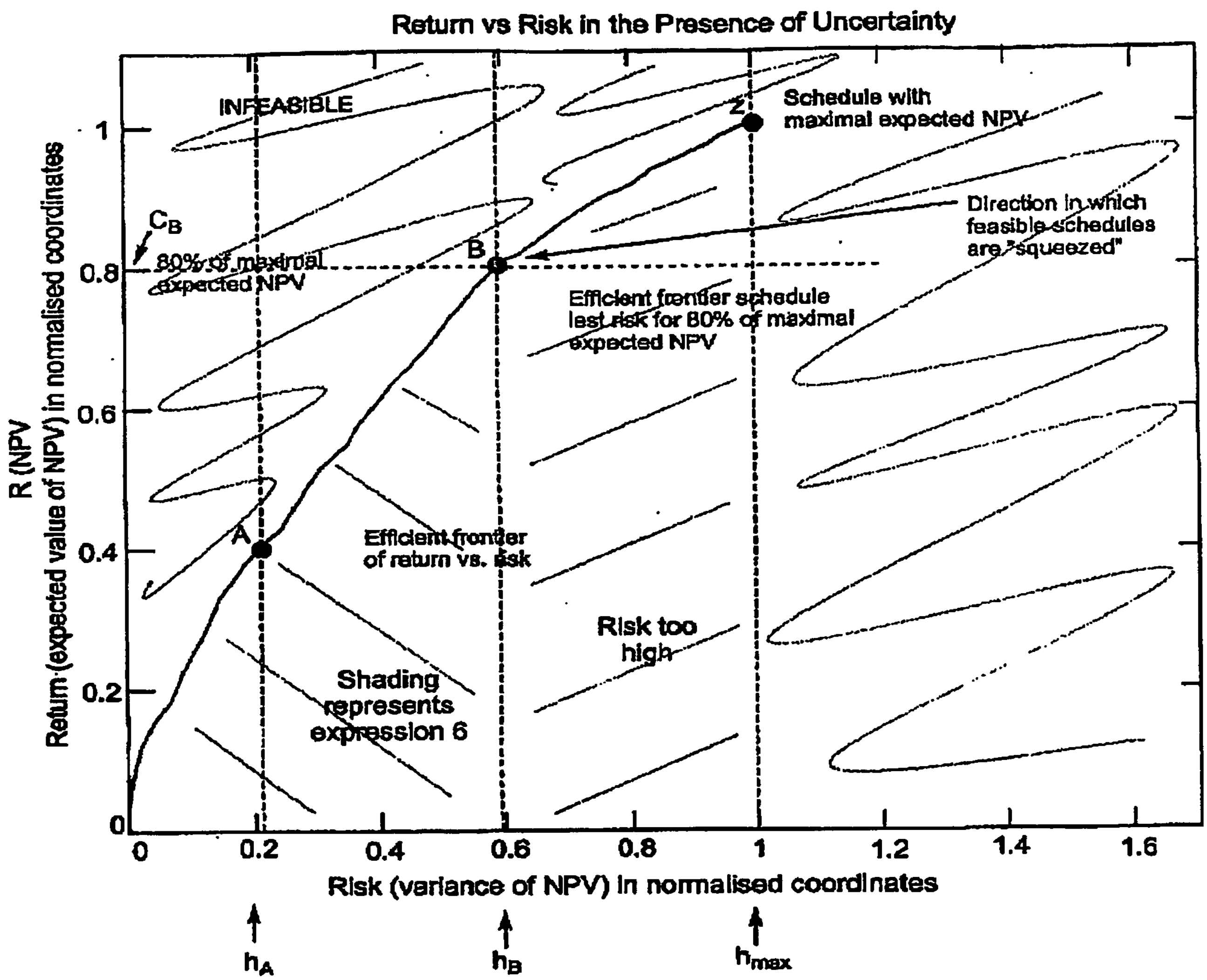


Figure 6


Return vs Risk in the Presence of Uncertainty
INFEASIBLE
Schedule with maximal expected NPV
Z
C_B
80% of maximal expected NPV
B
Direction in which feasible schedules are "squeezed"
Efficient frontier schedule lest risk for 80% of maximal expected NPV
A
Efficient frontier of return vs. risk
Risk too high
Shading represents expression 6
Return (expected value of NPV) in normalised coordinates
R (NPV
Risk (variance of NPV) in normalised coordinates
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
h_A
h_B
h_{max}